# Soil Quality Field Tools: Experiences of USDA-NRCS Soil Quality Institute

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## ABSTRACT

**The mission of the Soil Quality Institute (SQI) of the USDA Natural Resources Conservation Service is to develop and disseminate tools for soil quality assessment. In keeping with this mission, the SQI, through partnerships, has developed two assessment tools for use by farmers and field staff. We review these efforts here. The first, the *Soil Quality Card Design Guide*, provides a nine-step process for conducting workshops to guide farmers in the development of locally adapted soil quality assessment cards. The second, the *Soil Quality Test Kit Guide*, provides instructions and interpretations for 11 field tests representing physical, chemical, and biological properties of soil. In this paper, we present a summary of soil quality cards developed in seven states. An important strength of the soil quality card design process lies with the active participation of farmers to design the cards themselves as part of locally lead conservation activities. We also present results from soil quality test kit training workshops showing that the test kit provides an excellent framework for teaching soil quality concepts in the field. Regular use to compare effects of management systems or monitor changes over time will likely be limited to farmers with fairly high skill levels, specialists, and agricultural consultants.**

Soil quality was identified as an emphasis area of the USDA Natural Resources Conservation Service (NRCS) in 1993 with the establishment of the Soil Quality Institute (SQI). Trends of intensified crop production to meet world food demands, pressure on nonrenewable resources, and sustainable agricultural practices provide a long-term focus for soil quality goals. They are also important to other issues, including water and air quality, rangeland health, C sequestration, and climate change (Bezdicek et al., 1996; Doran et al., 1999; Herrick et al., 1999).

Farmers and ranchers need readily available technical tools and information for assessing and enhancing soil quality that can be easily integrated into their operations. Key technology components are: information on the concepts and indicators of soil quality; tools to assess, inventory, and monitor soil quality; information on the effect of management systems on soil quality; and agricultural practices to maintain or improve soil quality. In order to meet these needs, the SQI cooperates with partners in the development, acquisition, and dissemination of soil quality information and technology to help people conserve and sustain natural resources and the environment. Numerous information materials have been developed and are available at http://www.statlab.iastate.edu/survey/SQI/ (verified 26 Sept. 2001). Two assessment tools for use by farmers and other agricultural professionals are discussed in this paper.

The concept of soil quality is centered on the ability of the soil to perform specific functions. Karlen et al. (1997) proposed that soil quality be defined as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." Soil functions include sustaining biological activity; regulating and partitioning water flow; filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials; storing and cycling nutrients; and providing mechanical support for socioeconomic structures and protection for archeological treasures (Seybold et al., 1997).

Given the wide scope of functions encompassed in the definition, it would be difficult, if not impossible, to directly assess the quality of a soil. It is necessary to first identify the function(s) of interest and then select some set of indicators to observe and measure, thereby inferring the ability of the soil to perform that function. Several authors have proposed sets of soil quality indicators (Larson and Pierce, 1991; Doran and Parkin, 1994; Sarrantonio et al., 1996; Karlen et al., 1998). A common feature of the proposed indicator sets is that they all include some combination of physical, chemical, and biological soil properties, suggesting that for a soil to function effectively, all three components must be addressed. Assessing each of the chosen indicators is completed with a quantitative measurement, made either in the field or laboratory. This quantitative approach for assessing soil quality is well suited for trained professionals who can collect samples, conduct tests, interpret results, and make recommendations for management changes that will lead to improved soil quality.

Qualitative approaches for assessing soil quality have also been suggested (Garlynd et al., 1994; Harris and Bezdicek, 1994). In this approach, scientists and agricultural professionals work with land managers to identify and describe soil quality indicators in their own terms. The indicators they chose can be easily observed and rated qualitatively. This qualitative approach allows the land managers to develop simple guidelines that they can use to assess and monitor soil quality on their farms. While qualitative approaches are subject to internal bias, they have been found to compare well to quantitative measurements (Liebig and Doran, 1999). Qualitative approaches also have the advantage of making the farmer an active participant in the assessment.

The SQI, in cooperation with its partners, has developed both qualitative and quantitative assessment tools.

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**Abbreviations:** NRCS, Natural Resources Conservation Service; SCD, Soil Conservation District; SQI, Soil Quality Institute.

The *Soil Quality Card Design Guide* (USDA-NRCS, 1999) is a qualitative tool. The *Soil Quality Test Kit Guide* (USDA-ARS and NRCS, 1998) is a quantitative tool. Printed copies of these guides have been distributed to NRCS field offices and others as requested. Workshops have been conducted to train participants in their use.

## SOIL QUALITY CARD DESIGN GUIDE

### Guide Development

The *Soil Quality Card Design Guide*, in loose-leaf format, presents a step-by-step process for developing and marketing a soil quality card that reflects local soil conditions and farming practices. It outlines procedures and strategies to actively engage farmers and other land managers, along with agricultural professionals, in the development of the card.

The inspiration for the Design Guide originated with the Wisconsin Soil Health Score Card (Romig et al., 1995; Romig et al., 1996). The Wisconsin project was an outgrowth of a series of statewide listening meetings in which farmers expressed their concern for more research involving soil health. They stressed that practical knowledge of farmers should be integrated with scientists' analytical expertise. The project utilized a structured questionnaire to identify, from the farmers' perspectives, key properties describing healthy and nonhealthy soils (Garlynd et al., 1994; Harris and Bezdicek, 1994). The resulting soil health card included 43 indicators of soil quality reflecting soil conditions and farming systems in Wisconsin.

The SQI staff, in an effort to build on the work done in Wisconsin, decided to develop a procedural guide that could be used nationwide for the local development of soil quality cards. Three goals were established for the project: (i) the cards should be developed locally to reflect soil and cropping conditions in the area, (ii) local farmers and other agricultural professionals should actively participate together to develop the cards, and (iii) the resulting product should be a do-it-yourself tool that's easy to use.

A Soil Health Card Team comprised of the SQI staff, Oregon State University and Cooperative Extension Service researchers, University of Maryland researchers, and NRCS specialists was formed for the purpose of developing the guide. Between January 1997 and April 1998 the team designed and tested protocols for conducting farmer meetings, field-tested and released two soil quality cards, and prepared and released the document *Soil Quality Card Design Guide: A Guide to Develop Locally Adapted Conservation Tools* (USDA-NRCS, 1999). The guide contains background information on the soil quality card concept and principles of participatory learning. It provides detailed instructions for establishing a local soil quality card team to use the design guide in the development of its local soil quality card. The remainder of the guide book provides information for conducting a farmer meeting and designing, field testing, publishing, and marketing a soil quality card. The resulting product is a tool for farmers to record observations and then assess, compare, and monitor soil quality on their farms to help guide them in future management decisions.

The strength of the approach used lies in the facilitated farmer meeting. The focus of the meeting is on farmers and their perceptions and descriptions of soil quality. Agricultural professionals are members of the local soil quality card team and participate as technical advisors during the meeting. This process encourages in-depth dialog between agricultural professionals and farmers, allowing both to learn from each other.

### Card Test

To date, seven soil quality cards have been developed through the process described in the design guide. Each card was designed for use in all or part of the following states: Illinois, Maryland, Montana, North Dakota, New Mexico, Ohio, and Oregon. Each card contains a list of soil quality indicators with a set of descriptive terms for each indicator defining three levels of soil quality, such as *good*, *fair*, and *poor*. Scores are generally on a numeric scale, with 1 through 3 as gradations of poor, 4 through 6 as fair, and 7 through 9 as good. Collectively, the seven cards have identified 32 physical indicators, 12 biological indicators, 9 chemical indicators, and 15 plant or residue indicators of soil quality. Table 1 provides a few examples. Many of the indicators are similar from card to card, but the descriptive terms for the indicators are unique to each card, reflecting indigenous farmer terms and concepts. The cards also contain instructions for use, including advice on appropriate seasons and field conditions for making observations. There is also a section provided for recording management and site information for each field observed. Farmers who participated in the meetings generally decided not to devise a system for developing a composite score for a site but rather preferred to have individual ratings for each indicator so that they could identify specific aspects of soil quality that need improvement.

The soil quality cards that have been developed are useful tools for a farmer to compare different management effects on the same kind of soil, troubleshoot problem areas in fields, and monitor change over time where new management systems are begun. An assessment using the card can typically be completed in less than 10 minutes. Observations should be made at the same location and time of year and under similar moisture conditions. Use of the card helps farmers to see the impacts of different management systems on soil. It also helps farmers to view soils in the context of physical, chemical, and biological properties. Since the card is developed by farmers with assistance from other agricultural professionals, it provides a framework and language for enhancing communication between the two groups. The process of developing the card provides a tool for introducing farmers to the concept of soil quality. Because it openly seeks out and places value on farmer opinions, it can lead to increased trust between landowners and other agricultural groups participating in the process. Agricultural professionals who represent

**Table 1. Examples of soil quality indicators and descriptive terms from soil quality.**

| Indicator | State | Descriptive terms: Poor | Fair | Good |
|---|---|---|---|---|
| Compaction | OR | Wire flag bends readily, obvious hardpan, turned roots. | Some restrictions to penetrating wire flag, some root growth restrictions | Easy penetration of wire flag beyond tillage layer. |
| Drainage, infiltration | MD | Water lays for a long time, evaporates more than drains, always very wet ground. | Water lays for short period of time, eventually drains. | No ponding, no runoff, water moves through soil steadily. Soil not too wet, not too dry. |
| Nutrient-holding capacity | MD | Soil tests dropping with more fertilizer applied than crops use. | Little change or slow down trend. | Soil tests trending up in relation to fertilizer applied and crop harvested. |
| Salinity | ND | Areas of no crop growth with Kochia and bare saline spots visible throughout field, poor drainage, high water table. | Areas of stunted crop growth and saline spots on headlands and around potholes and ditches. | Crops adjacent to potholes or road ditches not stunted, good internal drainage. |
| Soil organisms | MT, ND | Few insects, worms, or fungi. | Some insects, worms, and fungi. | Many insects, worms, and fungi. |
| Earthworms | IL | 0–1 per shove. | 2–10 per shovel | >10 per shove. |
| Residue decomposition | OH | Rapid decomposition with little or no visible residue in the topsoil or very slow decomposition with relatively unweathered residue in the topsoil. | Some visible, nondecomposed residue in the topsoil. | Residue at various stages of decomposition on soil surface and in the topsoil. |
| Crop vigor | OR | Stunted growth, discoloring, uneven stand. | Some uneven, stunted growth; slight discoloring. | Healthy, vigorous, and uniformly growing plants. |

government agencies find that the card can provide a nonprogram context for approaching and working with new farmers to solve resource problems.

Drawbacks of the soil quality cards are few but are important to consider. The card is not intended for comparisons of observations made by different farmers. Due to the subjective nature of the ratings, the same individual should make the observations. Because only a small group of farmers are involved in developing the card, future modification may be required as it is used by more individuals over more kinds of soils because important indicators may have been omitted (Romig et al., 1996). To accommodate this possibility, the soil health cards generally include space for adding new indicators. Romig et al. (1996) also noted that the card represents the perspective of soil quality as perceived by farmers. Since the concept of soil quality encompasses virtually all functions that soils provide, other user groups may have different perspectives. For example, the presence of salts would tend to be viewed as an indicator of poor soil quality to the farmer while others may view it as a positive feature if the function of interest is habitat for rare halophytic plant species.

Because the soil quality cards have only recently been released for use, effectiveness as a conservation tool cannot currently be determined. The measure of their effectiveness should be improvements in soil conservation and a better understanding of management effects on soil quality among farmers and not frequency of card use.

## SOIL QUALITY TEST KIT GUIDE

### Guide Development

A field test kit, for measuring selected soil quality indicators, was developed by Dr. John Doran of the USDA-ARS. The concept for the kit, description of tests, and results from field testing are presented by Cramer (1994a, 1994b, 1994c) and Sarrantonio et al. (1996). The purpose in developing the test kit was to provide farmers with a tool that would be simple to use, inexpensive, and provide rapid results. From the farmer's perspective, the tests should be meaningful in the context of his or her understanding of soils and related processes. From the researcher's perspective, the tests should be reliable, have an acceptable range of accuracy, and be interpretable (Sarrantonio et al., 1996).

The kit was designed as a screening tool for soil quality at the field and farm level. Within that context, the kit can be used in several ways. It can be used to compare one field to a reference condition such as a cropped field to a pasture or native area with similar soil and site characteristics. The kit can be used to monitor changes at one location over time as a result of a change in land use or management. It can also be used to troubleshoot problem areas, such as small areas where crop stands are poor within a field.

Results obtained with the test kit compare well to those from standard laboratory analyses. With the exception of soil respiration, no differences were found between test kit and laboratory measurements for indicators included in the field test kit (Liebig et al., 1996). Furthermore, repeatability and overall variation of kit measurements was found to be similar to laboratory measurements.

From 1996 to 1998, the SQI and USDA-ARS cooperated to adapt the test kit for general use by NRCS field staff and others. The original instructions were modified, and interpretations of each indicator were developed. Additions to the original kit include tests for aggregate stability and slaking, an earthworm count, and instructions for describing physical characteristics of soil.

As part of these efforts, the SQI produced the *Soil*

*Quality Test Kit Guide* (USDA-ARS and NRCS, 1998), an illustrated booklet in loose-leaf form. Part I of the guide ("Test Procedures") contains instruction on site selection and sampling strategies; detailed illustrated procedures for performing 10 tests and a set of soil profile observations; suggestions for either obtaining kit components from commercial vendors or building a kit from readily available materials; and worksheets for recording site descriptions, test results, and physical soil profile observations. The test procedures include two biological indicators (soil respiration and earthworm counts), five physical indicators (infiltration rate, soil bulk density, water content, slaking, and aggregate stability), and three chemical indicators (soil pH, electrical conductivity, and soil $NO_3^-$–N). Instructions are provided for recording soil physical observations in the upper 30 cm for topsoil depth, rooting patterns, penetration resistance (with a wire rod), structure, and texture. Also presented are water quality measurements for $NO_3^-$, $NO_3^-$, and salinity. Part II of the guide ("Background and Interpretive Guide for Individual Tests") discusses each procedure individually. Background information about the property tested, factors affecting test results and any appropriate cautions, general information to aid in interpreting the results, and selected references for further reading are included.

In addition to detailed test procedure instructions, guidance is provided regarding overall sampling strategies. First, it is important that the individual identify the purpose for the testing—comparison with a standard condition or a different management practice, monitoring one location over time, or troubleshooting problem areas. Next, it is important to complete a site evaluation including factors such as identifying different soil map units present in the area of interest; management history; signs of erosion, deposition, or other disturbance; topography; location; and climate. The site evaluation is critical because it is generally only practical to make a limited number of observations. (We recommend a minimum of three.) It is important that the overall variation of the site be considered and that sample sites be selected to represent the area well. Timing of the test procedures is also important to consider. The results for specific tests will vary depending on when the tests are performed due to temporal changes for the indicator being measured (Sarrantonio et al., 1996). While each test may have a different optimum time to be conducted, from a practical standpoint, it is likely that all tests will be conducted at once as an annual soil quality assessment. When timing this assessment, one should consider the specific concerns being addressed and the combination of indicators to be observed. For an annual assessment to be meaningful, it should be conducted at the same time each year (Sarrantonio et al., 1996).

Once the locations for the tests are determined, the field sampling can be accomplished in about 1 to 2 h per location. However, this can vary considerably depending on the skill of the individual performing the tests and the local site conditions. The test procedures are presented in the guide in the same order as they are recommended to be performed in the field for maximum time efficiency. An additional 2 to 3 h is required later for drying and sieving samples to determine aggregate stability and slaking and for completing calculations for bulk density, water content, $NO_3^-$ concentration, and temperature-moisture adjusted respiration rates. Field tests apply to the top 7.5 cm of the soil. Infiltration rate and soil respiration measurements are conducted within a metal ring that is 15 cm in diameter. Samples for other tests are collected within close proximity to the ring, unless composite samples from the field are desired for tests of pH, electrical conductivity, and soil $NO_3^-$–N. The earthworm count requires the largest sample size, approximately 0.03 $m^3$. Soil physical observations are made from a shallow (30 cm) excavation.

## Kit Test Results

The SQI staff conducted more than 20 training sessions and demonstrations of the test kit following the procedures in the kit guide. Participants included consultants and Cooperative Extension Service personnel as well as employees from NRCS, Soil and Water Conservation Districts (SWCD), the Nature Conservancy, local governments, and universities. Students, farmers, Boy Scouts, and others have also been involved. In addition to its obvious use in evaluating soil quality indicators in the field, the kit is also an excellent educational tool to promote awareness of soil quality and the impacts of management on the soil resource. From our experiences in training and demonstrations, we found that the test kit and guide provide a vehicle for introducing the concept of soil quality. It is particularly useful for presenting the holistic context of physical, chemical, and biological properties of soils and their importance to soil functions. We found that many who have received training tend to view soils in terms of inherent properties (such as texture, depth, and drainage class) or suitability for a particular use. There is less understanding regarding the impact of management on the soil resource itself (except as it relates to erosion) and the realization that soil quality indicators can be changed through improved management practices, thus leading to improved functioning of soil.

Field personnel within NRCS have generally not yet adopted the use of the kit on a widespread basis. While those who received training in the use of the kit generally see it as a promising tool, there are two basic impediments to its use. First, many of our field employees do not feel that they can devote the necessary time in the field to one client to complete the field procedures. Secondly, the test kit is a new technology that requires follow-up support from technical specialists to help field personnel interpret test results under varying field conditions. It will take more time to develop a cadre of technical specialists, such as soil scientists and agronomists, in each state to provide this support. The kit has been used successfully in several locations, however. In 1999, two Soil Conservation Districts (SCDs) in North Dakota hired summer staff to use the test kit as a way to raise awareness and interest of local producers in soil quality issues. Participating farmers or ranchers received a *snap shot* of the current status of their soils.

The efforts in North Dakota have been very successful in helping producers evaluate the impact of different management systems on their soils (J. Stika, personal communication, 1999). Producers have been particularly interested in the use of the kit to troubleshoot problem areas in their fields. The interaction between the SCD employees and producers has led to enhanced opportunities to work with producers to improve farm management operations and positively impact local conservation priorities. It is interesting to note that this work is done outside the context of any particular USDA agricultural program. The interest by both the SCD and participating farmers is solely for the assessment of soil quality as impacted by management on an individual field or farm.

The test kit is also being used in New York City's Central Park after renovation of the Great Lawn and North Meadow where past soil compaction and erosion lead to sedimentation in several lakes in the park. Ninth- and tenth-grade students are using the kit as part of an educational program to establish baseline conditions and monitor changes in soil quality indicators through time in an effort by park managers to avoid similar problems in the future (L. Hernandez, personal communication, 2000).

## SUMMARY AND CONCLUSIONS

Soil quality can be assessed through the use of key soil properties, or indicators, that reflect important soil processes. The SQI of the USDA-NRCS has developed a qualitative tool (the *Soil Quality Card Design Guide*) and a quantitative tool (the *Soil Quality Field Test Kit Guide*) for soil quality assessment in the field. We know of seven soil quality cards that have been developed. We learned that farmers often link related features, or soil properties, in one indicator. For the farmer, properties such as drainage and infiltration are often inseparable for management and plant growth considerations, and thus are combined in one indicator even though these properties are often considered separately by researchers. Addressing the interrelationships between soil properties may be critically important for effective communication between scientists and farmers. It should be noted that an individual card reflects the work of only a small group from the region and may require revision as it is tested and used in the field. In addition, the cards described in this paper were developed primarily by farmers, and therefore emphasize the soil function of sustaining productivity.

Our experience indicates that workshops introducing the soil quality field test kit and guide are an effective vehicle for training in soil quality concepts and for describing the importance and interaction of physical, chemical, and biological components of the soil. We have also found it useful for raising awareness regarding the potential impact that management can have on individual indicators of soil quality. To date, the soil quality kit has not been widely used on a routine basis by NRCS field personnel. The time required to conduct tests in the field and the need for readily available technical support in interpreting results seem to be the main obstacles. The best results seem to be where technical staff specialists, such as soil scientists or agronomists, have been trained to use the kit as one of their tools when providing technical assistance to field office personnel in their assigned geographic areas.

The SQI will continue to work in partnership with others to develop information and tools such as those described here to help people conserve and sustain our natural resources and the environment.

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# Soil Quality for Sustainable Land Management: Organic Matter and Aggregation Interactions that Maintain Soil Functions

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## ABSTRACT

**Soil quality concepts are commonly used to evaluate sustainable land management in agroecosystems. The objectives of this review were to trace the importance of soil organic matter (SOM) in Canadian sustainable land management studies and illustrate the role of SOM and aggregation in sustaining soil functions. Canadian studies on soil quality were initiated in the early 1980s and showed that loss of SOM and soil aggregate stability were standard features of nonsustainable land use. Subsequent studies have evaluated SOM quality using the following logical sequence: soil purpose and function, processes, properties and indicators, and methodology. Limiting steps in this soil quality framework are the questions of *critical limits* and *standardization* for soil properties. At present, critical limits for SOM are selected using a commonly accepted reference value or based on empirically derived relations between SOM and a specific soil process or function (e.g., soil fertility, productivity, or erodibility). Organic matter fractions (e.g., macro-organic matter, light fraction, microbial biomass, and mineralizable C) describe the *quality* of SOM. These fractions have biological significance for several soil functions and processes and are sensitive indicators of changes in total SOM. Total SOM influences soil compactibility, friability, and soil water-holding capacity while aggregated SOM has major implications for the functioning of soil in regulating air and water infiltration, conserving nutrients, and influencing soil permeability and erodibility. Overall, organic matter inputs, the dynamics of the sand-sized macro-organic matter, and the soil aggregation process are important factors in maintaining and regulating organic matter functioning in soil.**

Soil quality is not a new topic. Early scientific endeavors recognized the importance of categorizing soil type and soil variables or properties in regard to land or soil use, especially for agricultural purposes (Carter et al., 1997).

The impetus to define and assess soil quality is in many ways derived from outside of the scientific community, being related to the concern of society with the overall quality or health of the environment. However, due to concerns with soil degradation and the need for sustainable soil management in agroecosystems, there has been renewed scientific attention to characterize soil quality. Placing a value on soil in regard to a specific function, purpose, or use leads to the concept of soil quality.

The basic idea of *fitness for use* in regard to agricultural use of soil, which was reflected in early and ongoing attempts at classifying *soil suitability* or *land capability*, is seen as a basic premise of soil quality (Larson and Pierce, 1991, 1994). If a soil is not suitable for a specific use, then it is not appropriate to attempt to assign or describe quality for that specific use or function. In many cases, however, it is not possible to make a perfect match between the soil and its intended use. Under these circumstances, quality must be built into the system using best management scenarios.

Ecosystem concepts such as function, processes, attributes, and indicators, have proved to be a useful framework to describe soil quality (Larson and Pierce, 1991, 1994; Doran and Parkin, 1994; Doran et al., 1996; Carter et al., 1997; Karlen et al., 1997). However, a precise definition of soil quality proves to be elusive. This is probably related to the innate difficulty in defining soil itself and to the multifaceted nature (i.e., scientific, personal, and social) of environmental concerns. Carter and MacEwan (1996) suggested that although soil quality describes an objective state or condition of the soil, it also is subjective, i.e., evaluated partly on the basis of personal and social determinations. The above framework of soil quality has utility when it is directed or focused towards the manipulation, engineering, and/or management of the soil resource. Thus, soil quality is a technology, an applied science, directed towards better soil management.

The objective of this paper is to review the context and approach to soil quality, with specific emphasis on soil organic matter (SOM) and soil aggregation. Specific objectives are to (i) trace the origins of soil quality research in the concern for sustainable land management in Canada, (ii) differentiate between descriptive and functional approaches used to characterize soil quality, (iii) evaluate the role and limitations of utilizing SOM as a key attribute of soil quality, and (iv) assess the factors that regulate SOM functioning in soil.

## SUSTAINABLE LAND MANAGEMENT AND SOIL QUALITY

Soil quality is considered a key element of sustainable agriculture (Warkentin, 1995). The latter refers to productivity, economic, social, and environmental components of land use systems (Smyth and Dumanski, 1995). Although sustainability issues are much broader than soil quality, the strong emphasis on maintaining the natural-resource base ensures that maintaining good soil quality is an integral part of sustainable agriculture (Miller and Wali, 1995).

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**Abbreviations:** SOM, soil organic matter.